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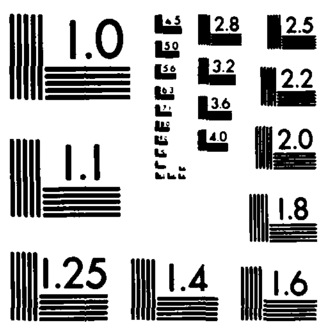

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AIR FORCE HUMAN RESOURCES LABORATORY

AD-A144 674

COMPARISON OF COLOR VERSUS BLACK-AND-WHITE VISUAL DISPLAYS AS INDICATED BY BOMBING AND LANDING PERFORMANCE IN THE 2B35 TA-4J FLIGHT SIMULATOR

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July 1984
Final Report for Period June 1980 – March 1983

Approved for public release; distribution unlimited

AIR FORCE SYSTEMS COMMAND
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Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY 2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
4. PERFORMING ORGANIZATION REPORT NUMBER(S) AFHRL-TR-84-22	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Operations Training Division Air Force Human Resources Laboratory 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State and ZIP Code) Williams Air Force Base, Arizona 85224	7b. ADDRESS (City, State and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Air Force Human Resources Laboratory 8b. OFFICE SYMBOL (If applicable) HQ AFHRL	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State and ZIP Code) Brooks Air Force Base, Texas 78235	10. SOURCE OF FUNDING NOS. PROGRAM ELEMENT NO.: 62205F PROJECT NO.: 1123 TASK NO.: 03 WORK UNIT NO.: 48

11. TITLE (Include Security Classification) Comparison of Color Versus Black-and-White Visual Displays as Indicated by Bombing and Landing Performance in the 2B35 TA-4J Flight Simulator

12. PERSONAL AUTHOR(S)
Kellogg, Robert S. Woodruff, Robert R. Kennedy, Robert S.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Yr., Mo., Day)	15. PAGE COUNT
Final	FROM Jun 80 TO Mar 83	July 1984	36

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB. GR.	bombing; chromaticity; computer generated image (CGI); flight simulation; landing; pilot performance; visual display

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Twenty-two highly qualified and experienced Navy instructor pilots were tested with respect to (a) bombing and (b) landing performance in the General Electric 2B35 TA-4J full-color wide-screen flight simulator. Half the pilots flew with color first and then black-and-white, the other half flew in reverse order. In Phase I of the study, repeated bombing runs were made and circular bombing errors obtained. In Phase II, repeated carrier-type landings were made and critical landing parameters were measured. Under the conditions of the study, no statistically significant differences were shown between performance with color or with black-and-white.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION

22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE NUMBER (Including Area Code)	22c. OFFICE SYMBOL
Nancy A. Perrigo Chief, STINFO Office	(512) 536-3877	AFHRL/TSR

DD FORM 1473, 83 APR EDITION OF 1 JAN 73 IS OBSOLETE.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

SUMMARY

The objective was to determine pilot performance effectiveness of color versus black-and-white in a wide-screen complex simulator, in the limited case of bombing and landing performance. With the proliferation of color computer-generated imagery (CGI) systems, there has been a trend toward the use of color systems in flight simulation. Research and development (R&D) exploring the utility of color in complex visual flight simulation was needed. The problem, in brief, was to gain sufficient information on the subject of color versus black-and-white in complex simulation to determine the utility of color presentation. Having such information would allow those in the Air Force who procure simulators to generate more realistic and cost-effective specifications.

The methodology here compared pilot performance using a color visual presentation with performance using black-and-white. Bombing and landing activities were chosen because of their high task loading and dependence on visual perception. In comparing these performance activities directly, an estimate of the effects of color presentation was possible. The test subjects consisted of 22 highly skilled and experienced instructor pilots, all of whom had undergone extensive weapons delivery training and were considered to be combat ready pilots. In the case of bombing, they flew a rectangular bombing course, half of the runs being in color and half in black-and-white. Circular bombing error was determined on each run. In the case of landing, five different parameters were measured: (a) air speed at touchdown, (b) angle of attack at touchdown, (c) vertical speed at touchdown, (d) lateral distance from the centerline of the runway at touchdown and, (e) longitudinal distance from the ideal touchdown point. Again, half the runs were made in color and half in black-and-white.

The findings were consistent throughout all test conditions: there were no significant performance difference between the color and black-and-white conditions. Under the specific circumstances of this R&D, color does not appear to augment performance. It cannot, of course, be generalized from these findings that color has no value in complex simulations. More R&D will be necessary in high fidelity, high resolution complex color systems in order to come to a valid understanding of the full utility of color in complex flight simulation.

It is concluded that color visual scene presentation, within the limits of this R&D, does not enhance performance. Based on these findings, it is recommended that the tasks of landing and range bomb delivery not be used as justification for color in a flight simulator visual system.

A1

PREFACE

This research and development (R&D) represents a portion of the R&D program of the Air Force Human Resources Laboratory Technical Planning Objective 3, the thrust of which is aircrew training. The general objective of this thrust is to identify and demonstrate cost-effective training strategies and training equipment capabilities for use in developing and maintaining the combat effectiveness of Air Force aircrew members. More specifically, the work was part of the R&D program conducted under the Air Combat Training Research subthrust, which has as its goal to provide a technology base for training high level and quickly perishable skills in simulated combat environments. The purpose of this effort was to compare pilot performance in bombing and landing in the 2B35 TA-4J flight simulator, using either a color or a black-and-white visual display. Mr. James F. Smith was the project scientist; Mr. Robert Woodruff was the task scientist; Dr. Robert S. Kellogg was the principal investigator. Dr. Robert S. Kennedy collaborated in the planning and analysis of the data.

The authors wish to express appreciation for the helpful cooperation of U.S. Navy personnel at the Naval Air Training Department, Naval Air Station, Chase Field, Texas and to Dr. David C. Hubbard, the University of Dayton Research Institute, and Messrs Dick Greatorex, AFHRL/OT, and Tien-Fu Sun, Singer Company, who performed the data analysis.

TABLE OF CONTENTS

LIST OF TABLES

COMPARISON OF COLOR VERSUS BLACK-AND-WHITE VISUAL DISPLAYS AS INDICATED BY BOMBING AND LANDING PERFORMANCE IN THE 2B35 TA-4J FLIGHT SIMULATOR

I. INTRODUCTION

With the proliferation of color computer-generated imagery (CGI) systems, there has been a trend toward the use of color systems in flight simulation. The research with respect to the need for color in complex visual flight simulation has been inconclusive. Some studies show enhancement resulting from the use of color in some specific instances, while others show none at all. It seems clear that insufficient information is available at present to determine the utility of color in complex flight simulation. Furthermore, the answer is made more complicated not only because of the lack of psychophysical data on the subject, but because user acceptance of such color systems may be a substantial factor, in their effective use. The problem, in brief, is to gain sufficient information on the subject of color versus black-and-white in complex simulation to determine the utility of color presentation. Toward this end, this investigation, which involved comparisons of bombing scores and landing scores in both color and black-and-white presentations, was developed at the Operations Training Division of the Air Force Human Resources Laboratory (AFHRL/OT).

II. THE 2B35 TA-4J FLIGHT SIMULATOR

The General Electric Navy 2B35 light-valve-projected color system was used in the effort. This system consists of three full-color light-valve systems which are projected upon three back-lighted screens that surround the cockpit. The field of view presented to the pilot is 210° horizontal and 60° vertical. Continuity of the visual scenes between adjacent screens is maintained by video cursors and photo-electric sensors which prevent image drift. The visual presentation is repeated at the instructor's console, using three television monitors.

The heart of the system is the image processor, a high-speed special-purpose computer housed in seven standard equipment cabinets. A two-dimensional view of the simulated three-dimensional view of the world is computed from a digital data base that describes the visual environment. The image is computed 30 times per second in the form of standard color television video signals for 512 pictures elements along each of 485 active horizontal raster lines for the three display channels. Overall control of the system, data management functions, and initial simulation computation are performed by a general-purpose computation system consisting of a PDP-11/50 digital computer and related software, interface equipment, and peripheral devices.

A special computer program was written to remove the computer code for hues which then essentially made the system black-and-white. This change could be made on the system in less than 2 minutes time from color to black-and-white or vice versa. The luminous intensity of the projected image was checked with a sensitive photometer and held at the same level for both black-and-white and color.

III. SUBJECTS

The test subjects consisted of 22 highly skilled and experienced instructor pilots. All of them had undergone extensive weapons delivery training and were considered to be combat-ready pilots. Their ages ranged from 24 to 39 years and total flying time, from 650 to 9000 hours. They were all either Navy or Marine Corps aviators.

IV. PHASE I – BOMBING

The experimental sequence of the bombing study consisted of flying repeated runs around a 30° dive bombing course. The first run was initialized on the downwind leg to the target, and from then on, the pilot made continuous rectangular bombing patterns, with one forced-choice bomb release made on each run. The bomb target consisted of the typical concentric-circular target used on bombing ranges. Each pilot was briefed to fly repeated bombing runs and to hit all of the release parameters as closely as possible.

The 10 pilots used in Phase I were randomly assigned to one of two groups. Group one flew 10 runs with color; then 10 runs with black-and-white. Group two flew in reverse order. This allowed for order effect differences when analyzing the data. The time delay for changing to color or black-and-white was never more than 2 minutes in duration.

At the conclusion of the runs, each pilot was thoroughly debriefed with respect to the purpose of the study and was cautioned not to divulge any information concerning this study to the other instructor pilots.

V. PHASE II – LANDING

The experimental sequence in the landing study was similar to the bombing study, except that a simulated ground-based carrier landing was used instead of a bombing run. A "footprint" of the carrier landing deck was displayed near the threshold of a ground-based landing strip, and the pilot was instructed to land on the simulated deck, coming as close as possible to ideal landing parameters. On the first approach, the pilot was released on downwind to the landing area. Go-arounds were not permitted, so the pilot was forced to land on each approach. Also, the Fresnel Lens Optical Landing System ("meatball") was not used, since it would have reduced the pilot's reliance on the general visual scene content.

The sequencing of pilots to color and black-and-white was again randomized so that half of the 12 subjects were presented with color first and the reverse for the other half. A series of 10 landings was made in one condition and then 10 more landings were made in the second condition. The parameters measured were as follows: (a) V_1, airspeed at touchdown; (b) V_2, angle of attack at touchdown; (c) V_3, vertical speed at touchdown; (d) V_4, X lateral distance from the centerline of the runway at touchdown; and (5) V_5, Y longitudal distance from the ideal touchdown point. All of these parameters were typed out by the 2B35 computer immediately following the landing pass. The pilots were instructed to press for attainment of ideal landing parameters on each run.

VI. ANALYSIS AND RESULTS

The statistical design for Phase I and Phase II was a split-plot factorial with one between-subjects or grouping factor, order of presentation of visual systems (color first vs. black-and-white first) and two within-subjects factors, Visual System (color vs. black-and-white) and Trials (10 landings, or bombing passes, under each color condition).

In Phase I, bombing circular error was used as the dependent variable. Ten pilots were randomly assigned to one of two groups. The five subjects of Group I flew 10 runs with color and then 10 runs with black-and-white; Group 2 flew in reverse order. As can be seen from the first ANOVA table of the appendix, no significant effects were discovered in the Phase I analysis, indicating no differences in performance between color and black-and-white. Table 1 shows the observed means for each order and visual system combination.

Table 1. **Phase I Means – Bombing Circular Error Scores**

	Order (Group)	
Visual System	**Black & White First**	**Color First**
Color	177.4 ft	245.6 ft
Black and White	219.7 ft	213.5 ft

In Phase II, the five dependent variables for landing performance were airspeed, angle of attack, vertical speed, x-distance, and y-distance. Twelve subjects (six within each group) participated in the experimentation in Phase II. Each dependent variable was analyzed separately. There were no significant differences for performance in color vs. black-and-white for these dependent variable main effects. The only statistically significant results discovered in Phase II consisted of a Group (i.e., order of presentation) by Visual System interaction for airspeed and Y-distance. The three-way interaction was also significant for Y-distance (see last five ANOVA tables in the appendix). Tables 2 through 6 show the observed means for each order and visual system combination.

Table 2. **Phase II Means – Airspeed**

	Order (Group)	
Visual System	**Black & White First**	**Color First**
Color	130.8 kts	134.2 kts
Black and White	132.7 kts	133.4 kts

Note. Optimum Airspeed = 125 kts.

Table 3. **Phase II Means – Angle of Attack**

	Order (Group)	
Visual System	**Black & White First**	**Color First**
Color	16.7°	16.0°
Black and White	16.5°	15.9°

Note. Optimum Angle of Attack = 16.5°.

Table 4. **Phase II Means – Vertical Speed**

	Order (Group)	
Visual System	**Black & White First**	**Color First**
Color	524.5 ft/min	620.0 ft/min
Black and White	543.4 ft/min	606.4 ft/min

Note. Optimum Vertical Speed = 650 ft/min.

Table 5. **Phase II Means – X-Distance**

	Order (Group)	
Visual System	**Black & White First**	**Color First**
Color	5.7 ft	10.5 ft
Black and White	9.3 ft	10.2 ft

Table 6. **Phase II Means – Y-Distance**

Visual System	**Order (Group)**	
	Black & White First	**Color First**
Color	12.8 ft	27.7 ft
Black and White	71.8 ft	11.1 ft

VII. DISCUSSION

The results in Phase I and Phase II show no significant main effect differences in performance with color as compared with black-and-white. This effort has addressed only two specific sets of performance outcomes and cannot, of course, be generalized to all flight performance. For example, the requirements for low level, high speed flight may call into play greater use of color for effective performance in that complex arena. In addition, the limitations of resolution and color fidelity as well as color scene content in the system studied may be of importance as limiting factors. It would seem, however, that the two performance areas studied, bombing and landing, are sufficiently generic and heavily enough task loaded to be reasonably representative procedures and, thus, useful as a part of the overall evaluation of the utility of color in simulation.

A corollary aspect of color in simulation is simply user preference. Most of the pilots in this study preferred color. It was just more aesthetically pleasing to them. However, for a few pilots, just the reverse was true; they preferred black-and-white. The usual objection to color was that it was too "cartoonish" and thus not realistic and served subjectively as an invasive element in their flying performance. Clearly, the differences cannot be sorted out without the experimental use of high fidelity color simulation.

Aside from simply aesthetic considerations, color in flight simulation would seem to add to realism and more importantly to spatial orientation and velocity vector information available to the pilot. In general, the better the spatial orientation and velocity vector information available to the pilot, the better will be the potential for optimal performance. For this reason, it would seem important to carry out further studies in the more advanced research flight simulators which are capable of high resolution, high quality and full spectrum color, as well as enriched and expanded scene content. If such an effort is then coordinated with transfer of training effectiveness studies, a more accurate evaluation of the value of color in flight simulation can be made.

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APPENDIX: ANALYSIS OF VARIANCE (ANOVA) TABLES FOR PHASE I AND PHASE II RESULTS

PHASE I ANOVA - BOMBING CIRCULAR ERROR SCORES

Source	df	SS	MS	F-value	p-value
Group (G)	1	100396.80	100396.80	2.45	.1541
Subj w/in groups	8	328017.37	41002.17		
Visual System (V)	1	1315.84	1315.84	.10	.7610
G by V	1	1156.81	1156.81	.08	.7744
V by Subj w/in groups	8	109490.87	13686.36		
Trials (T)	9	45075.80	5008.42	.59	.8627
G by T	9	48563.84	5395.98	.63	.7671
T by Subj w/in groups	72	614626.03	3536.47		
V by T	9	95671.40	10630.16	1.37	.2184
G by V by T	9	42785.98	4753.99	.61	.7843
V by T by Subj w/in groups	72	559664.93	7773.12		

PHASE II ANOVA - LANDING AIRSPEED

Source	df	SS	MS	F-value	p-value
Group (G)	1	264.60	264.60	.85	.6197
Subj w/in groups	10	3099.58	309.96		
Visual System (V)	1	15.00	15.00	.68	.5678
G by V	1	126.15	126.15	5.75	.0358
V by Subj					
w/in groups	10	219.25	21.93		
Trials (T)	9	209.68	23.30	1.85	.0690
G by T	9	178.90	19.88	1.58	.1325
T by Subj					
w/in groups	72	1131.42	12.57		
V by T	9	44.00	4.89	.36	.9514
G by V by T	9	236.18	26.24	1.92	.0581
V by T by Subj					
w/in groups	72	1228.41	13.65		

PHASE II ANOVA - ANGLE OF ATTACK

Source	df	SS	MS	F-value	p-value
roup (G)	1	25.35	25.35	.85	.6170
ubj w/in groups	10	298.63	29.86		
isual System (V)	1	1.35	1.35	.40	.5478
by V	1	.15	.15	.04	.8315
by Subj					
w/in groups	10	33.90	3.39		
rials (T)	9	8.15	.91	.80	.6182
by T	9	11.98	1.33	1.18	.3192
by Subj					
w/in groups	90	101.87	1.13		
by T	9	15.82	1.76	1.62	.1224
by V by T	9	10.85	1.21	1.11	.3652
by T by Subj					
w/in groups	90	97.93	1.09		

PHASE II ANOVA - VERTICAL SPEED

Source	df	SS	MS	F-value	p-value
Group (G)	1	376516.82	376516.82	1.52	.2445
Subj w/in groups	10	2474022.00	247402.20		
Visual System (V)	1	421.35	421.35	.01	.9279
G by V	1	15778.82	15778.82	.30	.6016
V by Subj w/in groups	10	527879.75	52787.97		
Trials (T)	9	381777.98	42419.78	1.56	.1399
G by T	9	374880.25	41653.36	1.53	.1492
T by Subj w/in groups	90	2450897.90	27232.20		
V by T	9	367225.69	40802.85	1.32	.2376
G by V by T	9	358854.69	39872.74	1.29	.2531
V by T by Subj w/in groups	90	2783428.80	30926.99		

PHASE II ANOVA - X-DISTANCE

Source	df	SS	MS	F-value	p-value
Group (G)	1	481.67	481.67	1.57	.2372
Subj w/in groups	10	3064.08	306.41		
Visual System (V)	1	160.07	160.07	1.57	.2377
G by V	1	244.02	244.02	2.39	.1505
V by Subj w/in groups	10	1020.22	102.02		
Trials (T)	9	1633.57	181.51	1.91	.0594
G by T	9	881.42	97.94	1.03	.4211
T by Subj w/in groups	90	8537.91	94.87		
V by T	9	1398.52	155.39	1.77	.0850
G by V by T	9	422.07	46.90	.53	.8471
V by T by Subj w/in groups	90	7911.09	87.90		

PHASE II ANOVA - Y-DISTANCE

Source	df	SS	MS	F-value	p-value
Group (G)	1	26775.94	26775.94	.29	.6054
Subj w/in groups	28	5052157.05	22158.58		
Visual System (V)	1	31258.83	31258.83	1.19	.3007
G by V	1	228598.53	228598.53	8.73	.0140
V by Subj w/in groups	10	261846.91	26184.69		
Trials (T)	9	290277.81	32253.09	1.96	.0525
G by T	9	283356.06	31484.01	1.92	.0590
T by Subj w/in groups	90	1478742.94	16430.48		
V by T	9	152802.00	16978.00	.82	.6043
G by V by T	9	451638.38	50182.04	2.41	.0168
V by T by Subj w/in groups	90	1873635.59	20818.17		

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